Overview of the Mobile Detection Assessment and Response System

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Abstract

The Mobile Detection Assessment Response System (MDARS) is a joint Army-Navy effort to field interior and exterior autonomous platforms for security and inventory assessment functions at DoD warehouses and storage sites. Based on a Cybermotion K2A Navmaster platform designed for singular operation in structured office environments, the MDARS Interior platform has incorporated additional collision avoidance, intruder detection and inventory assessment systems under a Multiple Robot Host Architecture (MRHA). The MRHA is a distributed multiprocessing system that provides coordinated control of multiple autonomous vehicles from a single host console. The increased functionality of the base platform required the addition of sensor equipment and accompanying distributed processing.

The MDARS Interior platform has successfully demonstrated sustained autonomous navigation within a semi-structured warehouse environment (with few walls and within which odd-shaped objects move about unpredictably) using a combination of path anomaly sensor recognition and path adaptation analysis algorithms. The interior platform has established the ability to recognize intruders using passive infrared heat and microwave motion detection sensors, and to respond in kind. The interior platform also performs warehouse inventory tracking and assessment through the use of interactive RF transponder tags and platform tag reader hardware.

The MDARS Exterior platform will incorporate much of the functionality of the Interior platform, although vehicle construction, sensor suite configuration, navigation, and assessment implementation will vary greatly from that of its interior predecessor. Development of the first prototype vehicle for the MDARS Exterior Program has been initiated under a Broad Agency Announcement (BAA) contract with Robotic Systems Technology, Inc. Application of intelligent vehicle highway-based sensor technology, global and local navigation techniques are currently being evaluated and refined.

Background

The MDARS program is managed by the US Army Physical Security Equipment Management Office (PSEMO), Ft. Belvoir, VA, with the Naval Command Control and Ocean Surveillance Center (NCCOSC) providing all technical direction and systems integration functions. The MDARS Interior development effort (MDARS-I) is specifically targeted to warehouse interiors, with the Exterior effort (MDARS-E) addressing outdoor storage areas.

MDARS-I

The MDARS program was initiated via the Interior effort in 1989 under the auspices of improving the effectiveness of a shrinking security guard force and significantly reducing the intensive manpower requirements associated with accounting for critical and high-dollar assets [Everett, 1995]. Functional requirements include the emulation of personnel performing the following tasks: 1) intruder detection, assessment and response, and 2) product inventory for loss/theft prevention purposes. Operating out of a warehouse test-site (Figure 1) at Camp Elliott, San Diego, CA, the program has established a supervised-autonomous patrol, rudimentary intruder detection capabilities, and the initial product (automated inventory) assessment system. In 1995, a Broad Agency Announcement (BAA) contract was awarded to Cybermotion, Inc., Salem, VA, to improve the probability of intruder detection, and to integrate the capability to perform automated inventory assessment using a platform-mounted interrogator and interactive RF transponder tags attached to warehouse inventory.

FIGURE 1. MDARS Interior robot patrolling in the Camp Elliott warehouse in San Diego.

MDARS-E

The MDARS Exterior effort began in early 1994 with the award of a BAA contract to Robotic Systems Technology, Westminster, MD, for the development of two brassboard platforms (Figure 2) equipped with autonomous navigation, collision avoidance, and intruder detection capabilities [Myers, 1994; 1995]. A preliminary prototype was successfully demonstrated in October 1994 and several component-level sensor systems have been evaluated off platform. The goals and functional requirements of the Exterior program parallel those of the Interior program though both are tailored for their respective target environments. As is the case for the Interior program, the goal of minimum human involvement dictates that the Exterior system operate in a supervised-autonomous mode. NCCOSC is expanding the host architecture initially developed for the Interior program to provide supervisory command and control functions for the exterior robots [Heath-Pastore & Everett, 1994]. The final system will be capable of supporting a mix of interior and exterior platforms to offer site commanders optimal capability and flexibility in an automated security solution.

Multiple Robot Host Architecture

The initial configuration of the MDARS Multiple Robot Host Architecture (MRHA) will support up to eight robotic platforms operating concurrently (with plans for increasing functionality to support up to 32 interior/exterior platforms). This concurrency requires that the MRHA must be able to respond to events from several robots simultaneously. Distributed processing allows for computational load distribution among multiple resources and facilitates future system expansion through the incorporation of additional processors. Individual processors are connected via *Ethernet* LAN (Figure 3) using the IPX/SPX peer-to-peer communications protocol. The hierarchical distribution of function enables human supervision and interaction at different processor/console levels and facilitates the assignment of human response on a prioritized basis.

At the top of the hierarchy, the *Supervisor* computer is responsible for overall system coordination and graphical display of the "big picture", an iconicized representation of the site map and operating platforms (with associated amplifying information). The *Supervisor* has at its disposal a number of computing resources, such as one or more *Operator Stations*, two or more *Planner/Dispatchers*, a *Product Assessment Computer*, and a *Link Server*. The *Supervisor* and *Operator Stations* provide site management information and interaction (respectively) via graphical user interfaces which are similarly configured with user-friendly visual displays supporting point-and-choose controls for guard-

FIGURE 2. MDARS Exterior Vehicle.

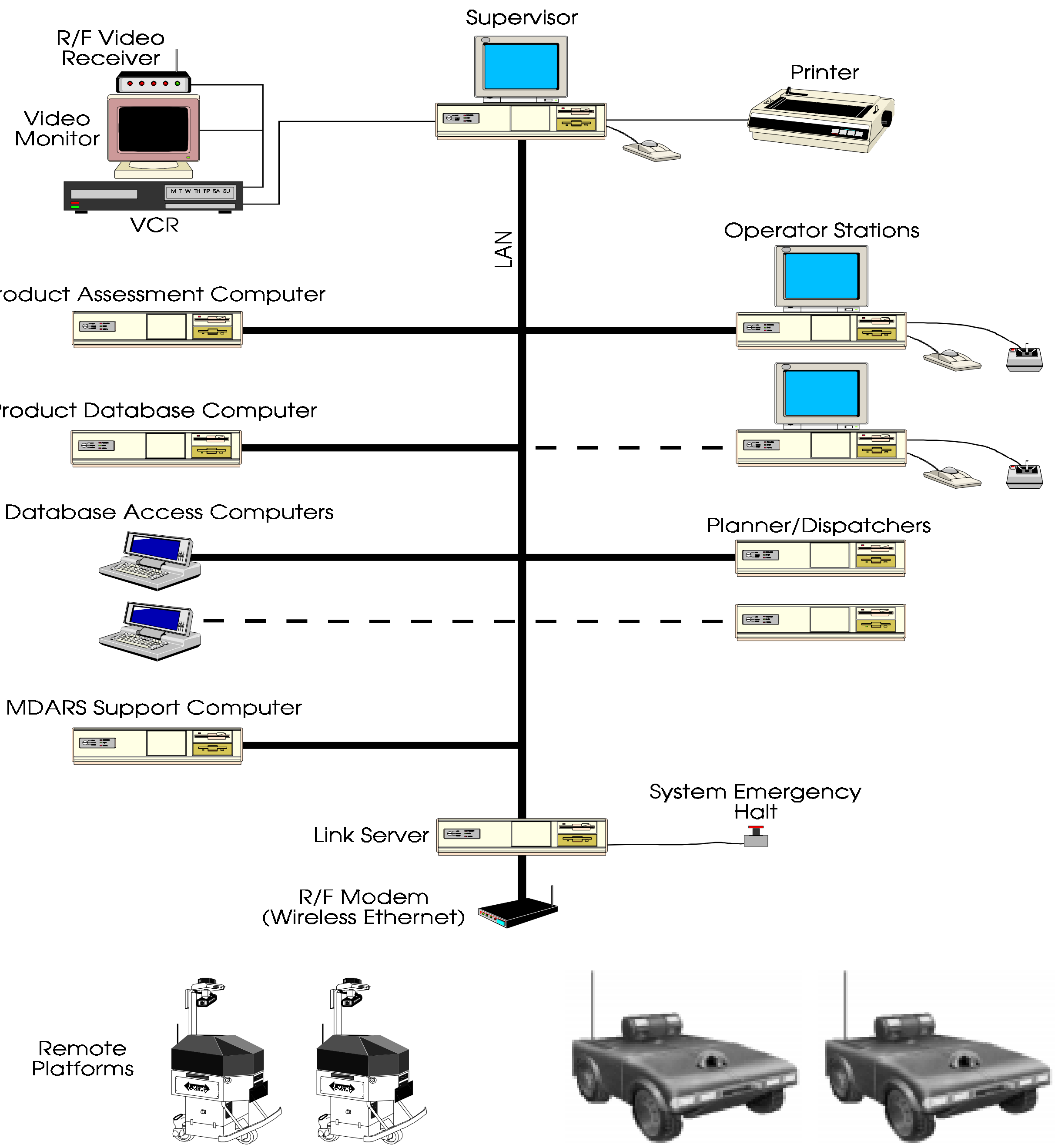

FIGURE 3. Block diagram of the Multiple Robot Host Architecture developed at NCCOSC for the coordinated control of multiple platforms.

selectable options and commands. The *Operator Station* provides host control, allowing a security guard/user to directly influence the actions of an individual platform with hands-on control of destination, mode of operation, and detection assessment functions. The *Planner/Dispatcher* computers (an integration of the Cybermotion *Dispatcher* and the NCCOSC *Planner*) are responsible for navigation and collision avoidance. The *Product Database* computer maintains a listing of high-value inventory as verified by an RF tag reading system on board the robot, correlated to geographical location within the warehouse. The *Link Server* provides an interface to a spread-spectrum RF link between the host and the various robots, and maintains a blackboard data structure of robot status information for immediate retrieval by other computers on the LAN.

Several "non-deliverable" enhancements have been made to the MRHA to facilitate remote system monitoring and maintenance during final developmental testing prior to installation at the first user site. An optional *Virtual Reality Display* can be connected to the network, if desired, to provide a realistic three-dimensional model of the operating environment [Everett et al, 1993] and platform progress. The *MDARS Support Computer* provides a telephone interface to MDARS capable of performing calls for emergency event notification and receiving and processing incoming user-technician queries. The *MDARS Support Computer* also provides automated video switching capabilities for the purpose of observing robot platform progress using fixed surveillance cameras that cover a patrol area.

Video from a steerable camera onboard the robot is also routed on a separate channel back to the control center. Both video channels are input to a *Gyyr FasTrans 2000* remote video surveillance system that is capable of transmitting a single selectable channel to a remote monitoring station over ordinary telephone lines. This remote monitoring feature allows operators or technicians to view live video of an installation site from their home office while performing diagnostic or maintenance activities.

Navigation

MDARS-I

The MDARS Interior project capitalizes on the mappable nature of the target environment (semi-structured warehouses) which have definitive boundaries and permanent or semi-permanent structural navigational reference points. The base interior platform, a Cybermotion *Navmaster*, is equipped with preplanned virtual path capabilities designed to incorporate various potential guidance modes. The MDARS Interior project has integrated additional NCCOSC-developed autonomous obstruction recognition and path adaptation. Once the interior platform recognizes an obstruction, a history buffer of recent sensor data is uploaded from the platform to the *Planner/Dispatcher* computer which then plans an alternate unrestricted path to avoid the obstacle.

Because the base interior platform was designed for highly structured environments (with many walls) which afforded continuous closed-loop correction of odometric errors, the MDARS Interior project required supplemental navigational re-referencing to accommodate semi-structured operation in warehouse environments. The Interior project uses a lateral post detection technique that is inexpensive, both in terms of sensor hardware and processing power requirements. At the current test site, retro-reflective tape markers are attached to various immobile objects (mainly structural support posts) and integrated into virtual path segments. A Banner Engineering retro-reflective IR. proximity sensor is mounted on each side of the *Navmaster's* turret, perpendicular to the robot's direction of travel. Longitudinal position is updated upon detection of a known marker coordinate, while lateral position is inferred from side-looking sonar data [Gage et al, 1995].

MDARS-E

The collision avoidance problem for the MDARS Exterior program is much more complex than for the interior application, even in relatively structured scenarios. The collision avoidance strategy therefore incorporates a two-tier layered approach, wherein long-range (i.e., 0-100 feet) low-resolution sensors provide broad first-alert obstacle-detection coverage, and shorter range (i.e., 0-30 feet) higher-resolution sensors are invoked for more precise obstacle avoidance maneuvering. A reliable means of checking for oncoming and intersecting traffic is required for autonomous execution of unrestricted path planning. Doppler radar, laser ranging and video image processing are currently under consideration for these applications [Everett, 1995].

Intruder Detection

MDARS-I

The original MDARS Interior intruder detection system incorporated multiple sensor arrays (passive infrared (PIR), ultrasonic, acoustic, and microwave) each with enough fixed sensors to cover the entire 360-degree view around the robot, and video motion detection for fixed-sensor detection confirmation. In 1993, the decision was made to switch to the Cybermotion *SPI* (*Security Patrol Instrumentation*) module, developed under a Cooperative Research and Development Agreement between Cybermotion and

NCCOSC. The *SPI Scanner* is composed of a vertical array of PIR detectors, a K-Band microwave transceiver, and an optical flame detector [Everett, 1995] which rotates at one revolution per second. Early feasibility studies determined that the *SPI Scanner* was functionally equivalent to the original MDARS Interior "staring" array sensor suite, but the first commercial prototype (designed for highly structured office environments) failed to perform up to expectations when tested in a warehouse environment. The most prominent shortcoming of the prototype *Scanner* was mechanical robustness. In addition, the commercial pan-and-tilt units that interface to the *SPI* for positioning the camera were affected by vibrations induced by imperfections in the warehouse floor (cracks, pits, and vertically misaligned adjacent floor slabs are typical characteristics of the target environment). The early *Scanner* was also found to be less sensitive in detecting radially moving targets more than eight feet away.

Under the current BAA contract, Cybermotion is producing an improved system that combines the *Scanner* with an integrated pan-and-tilt-mounted surveillance camera enclosed together in a water-resistant cast aluminum housing with shock mounting. The *Scanner* is being reconfigured to include: 1) an additional PIR sensor oriented 180 degrees with respect to the existing sensor, 2) a higher-gain microwave antenna (developed by VSE, Inc.), 3) an upgraded CPU that provides the computing power required to run more sophisticated radial tracking algorithms, and 4) an improved slip ring [Holland et al, 1995].

<u>MDARS-E</u>

The intrusion detection system for the Exterior system will utilize several different and complimentary sensor technologies to detect the motion of intruders within a 6.6 to 328 foot range, 360 degrees around the stationary robotic platform.

Sensor technologies currently being evaluated include microwave, vision, and radar systems that can be used to detect motion, thermal signatures, pattern characteristics, and behavior over time. As with the obstacle avoidance solution, a two-layer sensing strategy is being pursued. The first layer provides a broad area alert and is characterized by fast angular coverage. The second layer affords a detailed assessment capability with high angular and range resolution.

Product Assessment System

The purpose of the MDARS *Product Assessment System* is to provide an automated means of establishing geographical location of specific items within a warehouse or exterior storage facility for routine comparison to a database of perceived inventory and assigned storage locations [Smurlo et al, 1995]. The *Product Assessment System* is composed of interactive RF inventory ID tags, tag probing components (Savi *Interrogators* and *Tag Reader Computers* located on the robotic platforms), host inventory assessment database, and user interface components (Figure 4).

Sensitive and high-value items are equipped with the RF transponder tags (the Savi Technologies *TyTag* for the Interior program and Savi *SealTags* for the Exterior program). Both tag units are equipped with onboard piezoelectric beepers that can be activated on command from an *Interrogator* to allow individual tags to be easily located by personnel [*Savi*, 1994b].

Each patrolling platform is equipped with a tag reading *Interrogator* and controlling *Tag Reader Computer*. The *Interrogator* issues a tag wakeup signal consisting of a 3.49-second pulse modulated at 30-KHz, then uploads data from responding tags. Savi's proprietary *Batch Collection* algorithm allows the system to accurately identify thousands of tagged assets at a single read location in a matter of minutes [*Savi*, 1993]. After a tag data collection is completed, the *Tag Reader Computer* uploads the buffered tag data from the *Interrogator* and packetizes the data into its onboard memory for subsequent collection by the *Product Assessment Computer* at the host console. Tag inputs received by the *Product Assessment Computer* are stored on the *Product Database Computer*. Inventory information may be manually input by personnel via the *Database Access Computer*. Tag collection inputs from patrolling platforms are reconciled with historical inventory data on the *Product Database Computer*. In January 1995, extensive testing was conducted by the MDARS development team at the Camp Elliott warehouse facility to assess the accuracy of several tag-position-estimation algorithms [Smurlo et al, 1995]. The test was also designed to determine the impact of performing tag-read operations at two different stop intervals (37.5 and 75 feet) along the route, using 173 Savi *TyTags* placed at known locations throughout the

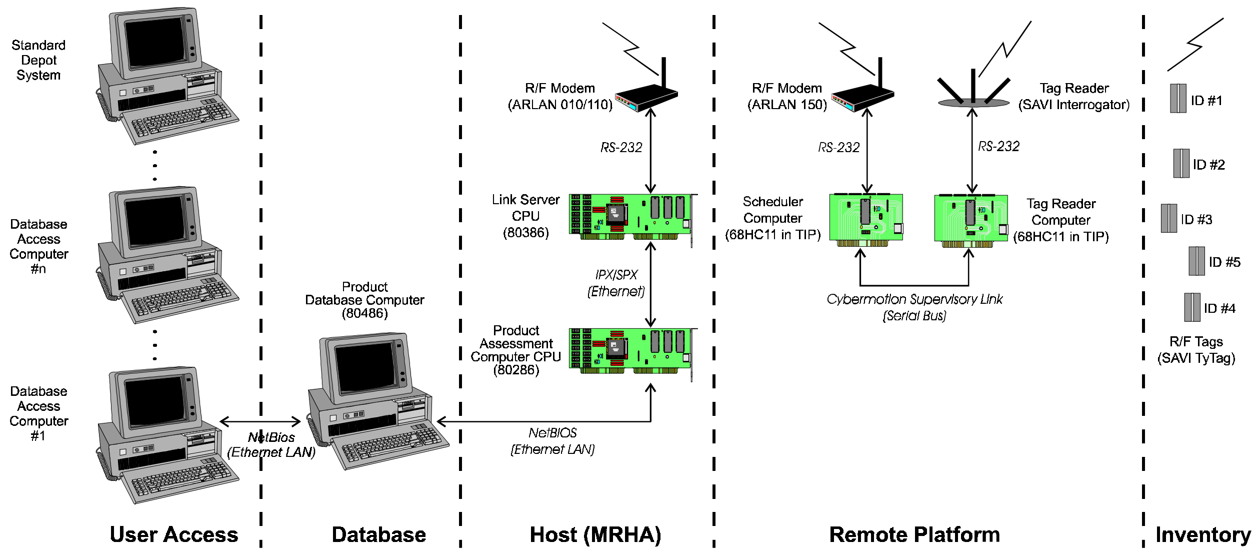

FIGURE 4. Block diagram of the MDARS Product Assessment System.

warehouse. For survey intervals of 37.5 feet, the best performing algorithm achieved an average of approximately 15 feet positional uncertainty (i.e., the difference between estimated and actual tag locations), while for survey intervals of 75 feet the uncertainty was increased to approximately 20 feet [Smurlo et al, 1995].

Conclusion

In this era of down-sizing, MDARS facilitates a reduction of manpower or a more effective distribution of human resources. The MDARS supervised-autonomous mode of operation combines the speed and precision of computer resources with human perception through limited user supervision. MDARS can significantly reduce the need for personnel to perform mundane, reiterative and costly tasks while increasing the effectiveness of such operations.

MDARS has the potential for removing humans from inherently dangerous situations or operating environments. With minimal additional resources, the concept can be enhanced and extended to target a variety of remote surveillance applications such as border patrol and law enforcement security. With commercial partners supplying critical application-specific technologies, a "spin-off" of MDARS could be capable of performing security functions in situations that currently are high-risk in terms of exposure of law enforcement personnel to potentially lethal situations, such as patrolling U.S. borders and providing situation assessment capabilities (i.e., remote audio/visual awareness) under hazardous conditions.

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